FINAL

IN-01-CR

207521

11P

NASA CONTRACTOR REPORT

NASA-CR-195198

ADVANCED BALLISTIC RANGE TECHNOLOGY

Leslie A. Yates

Eloret Institute
3788 Fabian Way
Palo Alto, CA 94303

Prepared for

Ames Research Center
under Cooperative Agreement NCC2-583

National Aeronautics and Space Administration

Ames Research Center
Moffett Field, California 94035

ADVANCED BALLISTIC RANGE TECHNOLOGY

Final Technical Report

for

Cooperative Agreement No. NCC2-583

for the period

January 1, 1989 - January 31, 1994

Submitted to

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California 94035

Aerothermodynamics Branch
Chul Park, Technical Monitor

Thermosciences Division
George S. Deiwert
James O. Arnold, Chief

Prepared by

ELORET INSTITUTE
3788 Fabian Way
Palo Alto, CA 94303
Phone: 415 493-4710
Fax: 415 424-9876
K. Heinemann, President and Grant Administrator
Leslie A. Yates, Principal Investigator

10 March, 1994

Introduction

The Hypervelocity Free-Flight Aerodynamic Facility (HFFAF) and the 16-Inch Shock Tunnel at NASA Ames Research Center provide invaluable data for verification of Computational Fluid Dynamics (CFD) codes with finite-rate chemistry and for studies of hypersonic flight. The HFFAF can duplicate the Reynolds numbers, Mach numbers, and enthalpies experienced in hypersonic flight in both Earth and Martian atmospheres, and it has provided information necessary for the design of hypersonic transports and advanced space transport systems. Two major advantages of the HFFAF are that the freestreams are clean and the projectiles are in free-flight; hence, there are no sting effects and the base flows are correct. The 16-Inch Shock Tunnel has been used for both flow field studies and force measurements on scale models of hypersonic vehicles. It has also been used for hypersonic propulsion studies.

From January 1, 1989, through December 31, 1993, research conducted under Cooperative Agreement NCC2-583 has supported these two facilities. The research topics range from methods for extracting aerodynamic information from ballistic range shadowgraphs to techniques that enable the one-to-one comparison of experimental images and CFD solutions. The work performed under this grant has been presented both at conferences and in publications, and it is summarized in the following sections.

Ballistic Range Data Analysis

The process of extracting aerodynamic coefficients from ballistic range tests requires multiple steps. First, orthogonal-view shadowgraphs are taken of the model as it flies down the test section. Recorded in these shadowgraphs are images of the model and of fiducial lines that are at known locations in the ballistic range. The positions of the

model images relative to these lines are measured, and these measurements are then transformed into the range coordinate system. The aerodynamic coefficients are obtained by fitting calculated trajectories to the range coordinates.

Prior to the work performed under this Cooperative Agreement, the methods used at NASA Ames Research Center for obtaining the model position from the shadowgraphs and for fitting a calculated trajectory to the range coordinates had not changed for twenty years. The position measurements were obtained using a manual method that was susceptible to user error. The aerodynamic parameter-identification routines did not have options to concurrently reduce multiple test runs or to allow for nonlinear aerodynamic coefficients. During the grant period, the film-reading and aerodynamic parameter-identification capabilities have been upgraded.

The old, manual film-reading system has been replaced with a new, computer-based system. With this new system, the shadowgraphs are digitized and displayed using a desk top computer. To improve the accuracy of the readings, least-squares techniques for measuring the model and fiducial-line locations have been incorporated into the film-reading software. Tests using the computer-based film-reading system indicate that the measurements obtained from the digitized shadowgraphs are more accurate than those obtained with the manual system, and the likelihood of user-induced error is minimized. The details of this system are described in Refs. 1 and 2.

The old, five-degree-of-freedom parameter-identification code has also been replaced. In the old parameter-identification code, the equations of motion were linearized and the aerodynamic coefficients were represented by average values. The average values were identified for each test run, and nonlinearities were identified by plotting the average coefficient for each test run versus the root mean square of the angle of attack for that run. In the new five- and six-degree-of-freedom parameter-identification codes, the equations of motion are not linearized and the aerodynamic coefficients are modeled by polynomial functions (other types of functions are also possible). The new

codes are capable of reducing multiple data sets concurrently; this capability is essential for accurate resolution of the parameters defining the nonlinear aerodynamic coefficients. These new codes also use a more accurate integration scheme (Burlisch-Stoer). The details of the new parameter-identification codes and their successful applications to tests with sharp and blunt cones, as well as lifting bodies, are detailed in Refs. 3-5.

The accuracy of the aerodynamic coefficients obtained from aeroballistic range tests has been improved by the upgrades in the film-reading system and the parameter-identification routines. The computerized film-reading system minimizes user-induced errors, and in the new parameter-identification routine, the aerodynamic coefficients are more accurately modeled and multiple data sets are used to identify the undetermined parameters. However, the accuracy of the aerodynamic coefficients can be compromised by inadequate modeling. Several methods can be used to specify mathematical models for the coefficients; the advantages and disadvantages of these methods are discussed in Ref.6.

Flow Field Analysis

For hypersonic and subsonic vehicles, flow-field structures (such as vortices, shear layers, and shocks) and the interaction of these structures with the vehicle affect the vehicle's performance. For example, flow separation and reattachment can affect the aerodynamics of the vehicle, increase heating in localized regions, and compromise the efficiency of the propulsion system. In addition, the flow can behave periodically or even chaotically (as in the case of vortex shedding), and serious control problems can result. Contained in Refs. 7-9 are discussions of the classifications of flow separation, the behavior of flow-field parameters near separation and in the resulting vortical flow, and the types of mathematical models that describe the time dependency of separated flows.

Constructed Images

For decades, experimental interferograms, schlieren, and shadowgraphs have been used for qualitative and quantitative studies of flow-field structures such as shocks, shear layers, and vortices. These experimental images are created by passing light through the flow field, and the recorded intensity patterns are functions of the phase shift and angular deflection of the light. In infinite- and finite-fringe interferograms, the recorded intensity patterns (fringes) are caused by phase shifts (optical pathlength differences). These phase shifts result from variations in the flow-field density and are proportional to path integrals of the refractive index. The path of integration is the path that the light follows through the flow field.

For two-dimensional and axisymmetric flow fields, point information can be extracted from interferograms and compared to computational results. The first step in extracting this information is to calculate the phase shifts from the interferogram's fringe patterns. These phase shifts can be obtained from either infinite- or finite-fringe interferograms. However, in flow-field regions where there are only small changes in the density and, hence, fractions of fringe shifts, calculating the phase shifts from finite-fringe interferograms will give more accurate results. A technique for extracting phase-shift information from finite-fringe interferograms is described in Refs. 10 and 11.

In schlieren and shadowgraphs, the intensity patterns (dark and light regions) are governed by the angular deflection of the light as it passes through the flow field. The angular deflection is proportional to the path integral of the refractive-index gradient. Flow-field features which have large refractive-index (density) gradients, such as shocks, shear layers, and expansion fans, are recorded in these images.

Both schlieren and shadowgraphs are used for flow-visualization studies and for locating flow-field structures. Schlieren contain sharp details of the flow-field structures as well as information concerning the direction of the light when it exits the flow.

Shadowgraphs also contain details of the flow field. However, they contain no information as to the direction of the light and are generally less sharp than schlieren. When these images are compared to computed flow fields, contour plots for only one plane of data (usually the symmetry plane) are typically used. The choice of contour levels can mask some of the features observed in the experimental images. In addition, if the flow is three dimensional or the model is free to roll, no single computational plane provides all the information necessary for realistic comparisons to experimental images.

During the grant period, software has been developed that constructs interferograms, schlieren, and shadowgraphs from CFD solutions. To minimize CPU time, the path that the light follows through the disturbed region of flow is assumed to not significantly deviate from a straight line path. Functions that describe the phase change and angular deflection are integrated along this line. The intensity patterns observed in interferograms, schlieren, and shadowgraphs are then related to these integrals. The algorithms used to construct these images are discussed in Refs. 11-12. Applications of these algorithms to a variety of flows are described in Refs. 11-13.

References

1. Leslie A. Yates, Tim C. Tam, John A. Cavolowsky, and Robert J. Miller, "*Advances in Film Reading and Interferometry at NASA Ames Research Center's Ballistic Range,*" presented at the 41st Meeting of the Aeroballistic Range Association, Oct. 22-25, 1990.

2. Leslie A. Yates, "*Development of an Automated Film-Reading System for Ballistic Ranges,*" Journal of Spacecraft and Rockets, Vol. 30, No. 2, March-April 1993; also presented as "*Improved Accuracy in Ground-Based Facilities - Development of an Automated Film-Reading System for Ballistic Ranges,*" AIAA Paper 92-4000, at the 17th AIAA Ground Testing Conference, Nashville, Tennessee, July, 1992.

3. Anthony W. Strawa, Greg A. Molvik, Leslie A. Yates, and Charles Cornelison, "*Experimental and Computational Results for 5 Degree Blunt Cones with Shock Generators at High Velocity,*" AIAA-Paper 89-3377, August, 1989.

4. Leslie A. Yates and Ethiraj Venkatapathy, "*Free-Flight Trim-Angle Predictions for the Aeroassist Flight Experiment,*" Journal of Spacecraft and Rockets, Vol. 29, No. 3, May-June 1992, pp. 335-343; also presented as "*Trim Angle Measurements in Free-Flight Facilities,*" AIAA Paper 91-1632, at the AIAA 21st Fluid Dynamics, Plasma Dynamics, and Lasers Conference, Honolulu, 6/1991.

5. James D. Packard, Wayland C. Griffith, Leslie A. Yates and Anthony W. Strawa, *"A Ballistic Investigation of the Aerodynamic Characteristics of a Blunt Vehicle at Hypersonic Speeds in Carbon Dioxide and Air,"* AIAA Paper 92-0328, presented at the 30th Aerospace Sciences Meeting and Exhibit in Reno, Nevada, January, 1992.

6. Gary T. Chapman and Leslie A. Yates, *"Nonlinear Aerodynamic Parameter Estimation and Model Structure Identification,"* presented at the AIAA Atmospheric Flight Mechanics Conference, Hilton Head, South Carolina, 7/92.

7. Gary T. Chapman and Leslie A. Yates, *"Topological Classification of Flow Separation on Three-Dimensional Bodies,"* Applied Mechanics Reviews, vol. 44, no. 7, pp. 329-345, July 1991.

8. Leslie A. Yates and Gary T. Chapman, *"Streamlines, Vorticity Lines, and Vortices Around Three-Dimensional Bodies,"* AIAA Journal, Vol. 20, No. 7, July 1992, pp. 1819-1826; also presented as *"Streamlines, Vorticity Lines, and Vortices,"* AIAA-Paper 91-0731, at the 29th Aerospace Sciences Meeting and Exhibit in Reno, Nevada, January, 1991.

9. Gary T. Chapman, Leslie A. Yates, and Michael J. Szady, *"Atmospheric Flight Dynamics and Chaos: Some Issues in Modeling and Dimensionality,"* in Applied Chaos, John Wiley and Sons, New York, 1992, pp. 87-141.

10. Tim C. Tam, Neal J. Brock, John A. Cavolowsky, and Leslie A. Yates, "*Holographic Interferometry at the NASA-Ames Hypersonic Free-Flight Aerodynamic Facility,*" AIAA Paper 91-0568, January, 1991.

11. Leslie A. Yates, "*Images Constructed from Computed Flowfields,*" AIAA Paper 92-4030, presented at the 17th AIAA Ground Testing Conference, Nashville, Tennessee, July, 1992.

12. Leslie A. Yates, "*Interferograms, Schlieren, and Shadowgraphs Constructed from Real- and Ideal-Gas, Two- and Three-Dimensional Computed Flowfields,*" presented at the FY92 Ames Technical Paper Contest for Women, 2/1992.

13. Surrendra P. Sharma, Steve Ruffin, Scott Meyer, Walter Gillespie, and Leslie A. Yates, "*Density Measurements in a Expanding Flow Using Holographic Interferometry,*" AIAA Paper 92-0809, presented at the 30th Aerospace Sciences Meeting and Exhibit in Reno, Nevada, January 6-9, 1992.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Advanced Ballistic Range Technology		5. Report Date 10 March, 1994 6. Performing Organization Code
7. Author(s) Leslie A. Yates		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address Eloret Institute 3788 Fabian Way Palo Alto, CA 94303		11. Contract or Grant No. NCC2-583 13. Type of Report and Period Covered 1/1/89 to 1/31/94
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C. 20456		14. Sponsoring Agency Code

15. Supplementary Notes

Point of Contact: Dr. Leslie A. Yates
c/o 230-2 NASA Ames Research Center, Moffett Field, CA 94035

16. Abstract

The research conducted under Cooperative Agreement NCC2-583 has supported two facilities at NASA Ames Research Center: the Hypervelocity Free-Flight Aerodynamic Facility and the 16-Inch Shock Tunnel. During the grant period, a computerized film-reading system has been developed, and five- and six-degree-of-freedom parameter-identification routines have been written and successfully implemented. Studies of flow separation have been conducted, and methods to extract phase shift information from finite-fringe interferograms have been developed. Methods for constructing optical images from Computational Fluid Dynamics solutions have also been developed, and these methods have been used for one-to-one comparisons of experiment and computations.

STAR Category 01

17. Key Words (Suggested by Author(s))	18. Distribution Statement
ballistic range CFD shadowgraphs schlieren	unclassified, unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
unclassified	unclassified		

*For sale by the National Technical Information Service, Springfield, Virginia 22161